

Pre-Permian Geology of the Bullio Area, New South Wales

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The oldest rocks in the Bullio area, the Byrnes Creek Formation (new name), comprise folded Ordovician distal flysch. Unconformably overlying this formation are shale, limestone and arenite of the Silurian Karalinga Formation (new name). In Late Silurian or Early Devonian time dacite and rhyodacite flows of the Bindook Complex spread discordantly over the area. This volcanic episode was associated with the emplacement of two granitic bodies — the Jemidee Microgranodiorite and the Mandari Granodiorite. Folding of the Silurian rocks possibly occurred at this time. Erosional remnants of the Permo-Triassic Sydney Basin succession unconformably overlie the older rocks in the eastern part of the area.

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INTRODUCTION

The Bullio area is located 100 km southwest of Sydney (Fig. 1) and includes a sequence of Ordovician and Silurian sedimentary rocks and Devonian volcanic rocks. A microgranodiorite intrudes both the sedimentary sequence and the volcanic rocks and a coarse-grained granodiorite of similar mineralogy intrudes the youngest unit of the Silurian sequence. These early-middle Palaeozoic rocks are unconformably overlain by the Permo-Triassic Sydney Basin succession.

Previous geological investigations in the Bullio area have been confined mostly to investigations of the Permian succession and associated coal and torbanite at Joadja (Wilkinson, 1891; Carne, 1903; Read, 1975; Robinson and Shiels, 1975). Mladek (1954) mapped the area and briefly described the major rock types but did not delineate the Palaeozoic rocks on his map. Editions of the Wollongong 1:250 000 Geological Sheet (Joplin *et al.*, 1952; Rose, 1966) showed the major rock types but gave little descriptive or interpretative geology in accompanying notes. McElroy and Relph (1961) mapped and described the area to the north of Bullio and several studies on the economic geology and petrology of the Bindook Complex in the Yerranderie district, 25 km north of Bullio, have been made (Harper, 1930; Edwards, 1953; Lawrence, 1953; 1965; Keaney, 1970; Jones *et al.*, 1977; Fergusson, 1980).

The aim of the present study was to map the pre-Permian rocks of the area in detail and to describe their petrology and stratigraphy. An interpretation of the structure and tectonic development of the area has also been made.

STRATIGRAPHY

The stratigraphy of the pre-Permian sedimentary and volcanic rocks in the Bullio area has not been delineated previously. Detailed mapping has allowed the recognition of one formation, the Byrnes Creek Formation, comprising the Ordovician strata and a second formation, the Karalinga Formation, comprising the Silurian

sequence. Lithological variations have allowed informal units to be recognized within both formations (Fig. 2). Two members have been recognized within the Devonian Bindook Complex.

BYRNES CREEK FORMATION (*new name*)

The Byrnes Creek Formation, which has a minimum thickness of 470 m, crops out along the Wingecarribee River and its tributary, Byrnes Creek, after which it is named. Along its western margin the formation is fault bounded, and in the east it is unconformably overlain by Silurian strata. Unfossiliferous, folded, quartz-rich rocks, which range from low-grade regionally metamorphosed quartzarenite to black slate, are the dominant rock types. The type section crosses the Wingecarribee River and is taken from GR374919 to GR374195 on the Hanworth 1:25 000 Topographic Sheet.

An Ordovician age for the Byrnes Creek Formation is suggested on the basis of lithological similarity with the Ordovician Unit B sequences described by Crook *et al.* (1973).

The Byrnes Creek Formation has been subdivided into four informal units.

Unit A (100 + m) is the oldest unit and is a medium-grained quartzarenite which crops out immediately east of the faulted western contact of the Formation.

Unit B (100 m) conformably overlies Unit A and consists of black slate. At the base of this unit, grey quartzarenite laminated on a 0.5 to 5 mm scale and typical of Unit A, is interbedded with the slate.

Unit C (110 m) conformably overlies Unit B and is a well-bedded grey to dark grey fine-grained, partly laminated (1 to 5 mm scale) quartzarenite.

Unit D (160 + m), the youngest unit preserved, conformably overlies Unit C and consists of interbedded grey to brown quartzarenite and shale. The quartzarenite beds range in thickness from less than 50 mm to 300 m and typically show boudinage structure. The shale has a well-developed cleavage parallel to bedding.

Petrography. The quartzarenite of the Byrnes Creek Formation is very well sorted and uniform in both composition and texture. Quartz grains, which constitute up to 90 volume percent and range in size from 0.01 to 0.5 mm, are partially recrystallized along their boundaries. Minor amounts of biotite, zircon, muscovite, tourmaline and garnet are also present. X-ray diffraction studies showed that the fine-grained matrix is composed of quartz, chlorite, illite, iron oxide and minor plagioclase. The absence of sand-sized feldspar grains distinguishes the arenite of the Byrnes Creek Formation from that of the overlying Karalinga Formation.

The shale is composed of illite, quartz and minor chlorite.

Sedimentary Structures. Slump folds with amplitudes from 30 to 50 mm are found in the fine-grained laminated quartzarenite of Units A, C and D.

In Unit B, small-scale (200 to 300 mm) cross-stratified quartzarenite is interbedded with coarser-grained, plane-bedded quartzarenite. Palaeocurrents determined from cross-laminated arenite (seven measurements) and corrected for tectonic tilt (Potter and Pettijohn, 1963) alternated between north-northeast and south. Angular intraclasts of the finer-grained arenite are found at the base of many planar beds. Ripples with internal cross-laminae, intraformational breccias, slump folds, small faults of less than 100 mm throw and load casts are found in Unit C. Graded bedding occurs in Units B and C.

Environment of Deposition. The fine-grained quartzarenite of the Byrnes Creek

ORDOVICIAN				SILURIAN				LATE SILURIAN — EARLY DEVONIAN				MID PERMIAN — TRIASSIC	
Unit D Unit C Unit B Unit A				Unit III Unit II Unit I Tugalong Limestone Member				Rileys Ridge Rhyodacite Member Pulpit Rock Dacite Member Sydney Basin Succession				Sydney Basin Succession	
BYRNES CREEK FORMATION				KARALINGA FORMATION				C O O L D P O O L D I N G B I N G					

Fig. 2. Idealized stratigraphic section for the Bullio area.

Formation is associated with black slate and this suggests deposition in a moderately deep water, anaerobic, marine environment.

KARALINGA FORMATION (*new name*)

The Karalinga Formation, with a minimum thickness of 550 m, unconformably overlies the Byrnes Creek Formation and is intruded by the Mandari Granodiorite. This formation is named after the property Karalinga, on which the type section crops out (composite type section from GR391929 to GR392924 and from GR400925 to GR403923 on the Hanworth and Barrallier 1:25 000 Topographic Sheets). It has been subdivided into one member and three informal units.

Tugalong Limestone Member (new name). The Tugalong Limestone Member (200 m), named after the property Tugalong, unconformably overlies the Byrnes Creek Formation and comprises a lower, brown to yellowish brown shale, a fossiliferous limestone and an upper, brown shale. The sub-unit boundaries are transitional and the upper shale grades into Unit 1 which conformably overlies it. The type section (GR391929 to GR392926 on the Barrallier 1:25 000 Topographic Sheet) crops out along the Wingecarribee River.

The contact between the Byrnes Creek Formation and the lower shale sub-unit of the Tugalong Limestone Member is not exposed but there is considerable evidence to suggest an unconformable relationship:

- (i) the mean strike of the Ordovician arenite is 060° whereas the mean strike of the Tugalong Limestone is 020°;
- (ii) at GR914374 the Ordovician strata are steeply dipping to the east whereas the Tugalong Limestone Member dips at 21° to the east; and

TABLE 1

Fossil assemblages found in the Tugalong Limestone Member. Localities are shown on Fig. 1.

Locality W	Locality Y	Locality Z
<i>Coenites</i> sp. indet.	<i>Heliolites</i> sp. indet.	<i>Favosites</i> sp. indet.
brachiopod fragments	<i>Tryplasma</i> sp. indet.	rhynchonellid brachiopods
syringoporoid corals	syringoporoid corals	
crinoid ossicles	crinoid ossicles	
	brachiopod fragments	
	pentamerid brachiopods	

(iii) small-scale cross-bed sets in the Ordovician strata show that they are overturned (i.e. younging to the west) whereas geopetal structures in *Tryplasma* sp. show that the Tugalong Limestone Member is right way up and younging to the east. Scheibner (1973a) has recognized an angular discordance between overturned Ordovician strata and Silurian sediments at Murruin Creek (30 km northwest of Bullio).

The basal 10 m of the limestone sub-unit consists of shale beds, 50 to 150 mm thick, interbedded with calcareous beds. In northeastern exposures the calcareous beds are reduced to flattened nodules, 100 to 150 mm in diameter, in a clay matrix. The limestone varies in colour from grey to dark grey and is composed of micritic and sparry calcite, terrigenous angular quartz, euhedral cubic pyrite and clay minerals. The shale sub-units are composed of clay minerals (mostly illite), micritic calcite and small amounts of quartz.

The basal 10 m of the limestone sub-unit is richly fossiliferous but only three localities have yielded fossils identifiable to generic level (Table 1) since deformation has compressed most fossils parallel to bedding. Calcareous shells and corals have been partially recrystallized. The fossils suggest a Silurian age for the Tugalong Limestone Member.

Deposition of the Tugalong Limestone Member occurred in a predominantly quiet, neritic environment which experienced periodic influxes of clastic sediment. Disarticulated and fragmented fossils indicate minor turbulence during the deposition of the basal 10 m of limestone.

Unit 1 (100+ m). The Tugalong Limestone Member grades vertically into an interbedded quartzarenite and shale unit in which the arenite to shale ratio increases upwards. Arenite beds range in thickness from 100 mm to 1.5 m. At GR392924 small-scale cross-bed sets in fine-grained arenite show that this sub-unit faces east. Ripples with internal cross-lamination are found in the shale.

Unit II (150+ m). Fine-grained laminated arenite, interbedded with coarser-grained massive arenite, conformably overlies Unit I. Graded beds, cross-laminated ripples and slump folds occur at several localities.

Unit III (50+ m). The youngest unit comprises interbedded arenite and shale. Arenite beds range in thickness from 10 mm to 1 m and predominate over shale beds which range in thickness from 50 to 500 mm. Asymmetrical linguoidal current-generated ripples (Table 2) with internal cross-laminae commonly occur in the shale. Palaeocurrents (six measurements) flowed towards the north.

Units I, II and III were probably deposited in a higher energy environment and shallower water than the limestone.

Petrography of Clastic Sedimentary Rocks. The arenite is a grey to dark grey indurated quartzarenite composed of subrounded to rounded quartz grains less than

TABLE 2

Ripple parameters for Unit III, Karalinga Formation. (6 readings).					
	Wave Length (mm)	Amplitude (mm)	Ripple Index	Ripple Symmetry Index	Straightness Index
Mean	180	17	11.9	3.7	4.6
Range	130-240	10-30	6.0-16.0	3.3-4.3	3.7-5.6

1 mm in diameter. A matrix of illite, chlorite, and fine-grained quartz occurs between the framework grains. Minor amounts of plagioclase and K-feldspar are present. Accessory minerals include tourmaline, zircon and opaque minerals. Illite, chlorite and fine-grained quartz are the main constituents of the shale. Small amounts of feldspar are also present.

BINDOOK COMPLEX

The Bindook Complex consists of acid volcanic rocks and related intrusions which crop out in a meridional belt to the west of Bullio over an area in excess of 750 km². Mapping of the eastern edge of the Bindook Complex in the study area has shown that two volcanic phases can be recognized.

Rileys Ridge Rhyodacite Member (new name). The Rileys Ridge Rhyodacite Member, named after a ridge north of Bullio Station, crops out to the west of the Pulpit Rock Dacite Member and extends beyond the boundaries of the mapped area. (Type locality GR388959 on the Barrallier 1:25 000 Topographic Sheet.)

The Rileys Ridge Rhyodacite Member comprises fine-grained, grey porphyritic rhyodacite and minor dacite. Phenocrysts consist of quartz, plagioclase, orthoclase, oxyhornblende and minor amounts of biotite. Plagioclase phenocrysts have cores of andesine-labradorite (An₃₈ to An₅₄) and outer rims of oligoclase (An₂₀ to An₂₅). Broken phenocrysts and curved twin lamellae are common in plagioclase. β -quartz phenocrysts have large embayments and micro-fractures which are annealed with fine-grained quartz. Hypersthene is the dominant pyroxene and accessory minerals include zircon, chlorite, epidote, and black opaque minerals. Chlorite, clinozoisite and prehnite occur as secondary minerals.

Pulpit Rock Dacite Member (new name). This member crops out over an area of 6 km² west of the Byrnes Creek Formation and is named after Pulpit Rock, a large Permian outlier which overlies the dacite at GR393951 (Type locality GR398957 on the Barrallier 1:25 000 Topographic Sheet).

The Pulpit Rock Dacite member is a dark grey, fine-grained porphyritic dacite with minor rhyodacite. The dacite is composed of subhedral to anhedral phenocrysts of plagioclase, embayed β -quartz, hornblende (pleochroic scheme — α = pale green, β = green, γ = dark green to brown) and calcic clinopyroxene set in a fine-grained to aphanitic groundmass of orthoclase, plagioclase, quartz and biotite. Plagioclase with cores of andesine-labradorite (An₃₄ to An₅₆) and outer rims of oligoclase (An₂₀ to An₂₅) is twinned according to the Carlsbad, pericline and albite laws. Twin lamellae are curved and fractured and many grain boundaries show evidence of fracturing. Accessory minerals include epidote, zircon and opaque minerals. Clinozoisite, prehnite and chlorite occur as secondary minerals.

Rounded to angular clasts of rhyodacite occur in the Pulpit Rock Dacite Member. These clasts may represent volcanic debris incorporated in the dacite during

eruption and emplacement. Randomly oriented layering of the groundmass is present in several samples of the rhyodacite.

The dacite of the Pulpit Rock Dacite Member can be distinguished from the rhyodacite of the Rileys Ridge Rhyodacite Member by:

- (i) darker colour in hand-specimen;
- (ii) absence of hypersthene and oxyhornblende phenocrysts;
- (iii) presence of hornblende;
- (iv) lower percentage of quartz phenocrysts; and
- (v) lower percentage of biotite in the groundmass.

Although the contact between the two volcanic members can be delineated both in the field and by petrographic studies, the stratigraphic relationship between the members has not been determined. At Bungonia, 60 km to the south, hornblende dacite is younger than dacite without hornblende phenocrysts (Carr, Jones and Wright, 1980) and at Yerranderie hornblende dacite occurs stratigraphically above hypersthene dacite (Joplin *et al.*, 1952).

Mode of Emplacement. The Pulpit Rock Dacite and Rileys Ridge Rhyodacite Members are considered to be extrusive for the following reasons:

- (i) microscopic flow layering is present in the fine-grained groundmass of both members;
- (ii) β -quartz is present in both members;
- (iii) both members have fractured plagioclase phenocrysts and the Rileys Ridge Rhyodacite Member has fractured pyroxene phenocrysts;
- (iv) rounded fragments of dacitic composition are found in the Pulpit Rock Dacite Member and may represent volcanic ejecta;
- (v) the Rileys Ridge Rhyodacite Member contains spherulitic quartz, with an outer rim of radiating quartz crystals, which is similar to textures thought to result from the devitrification of glass shards; and
- (vi) at two localities within the Rileys Ridge Rhyodacite Member (GR377928 and GR413965) sub-horizontal layers separated by large joints show textural and colour differences and may represent flows.

Age of the Extrusive Rocks. Although there is no direct evidence for the age of the volcanic rocks in the Bullio area, it is probable that both the Pulpit Rock Dacite Member and the Rileys Ridge Rhyodacite Member were extruded no later than Early to Middle Devonian. Both members are part of the large Bindook Complex which has been correlated with Devonian igneous rocks elsewhere.

At Yerranderie the Bindook Complex and the associated sulphide mineralization have been extensively studied and correlation with several Devonian igneous complexes within New South Wales has been attempted (David, 1950; Joplin *et al.*, 1952). More recently O'Reilly (1972) has suggested a Late Silurian to Early Devonian age for toscanites and dacites along the western margin of the Bindook Complex and Jones *et al.* (1977) have ascribed an Early to Middle Devonian age to ash-flow tuffs and silicic volcanic rocks near Yerranderie. Carr, Jones and Wright (1980) suggested that the Tangerang volcanics at Bungonia, dated at early Devonian, are a correlative of the Bindook Complex.

INTRUSIONS

Two episodes of intrusive activity can be recognized in the Bullio area. These

intrusions post-date the Bindook Complex volcanics and were emplaced prior to the deposition of the Mid-Permian Shoalhaven Group of the Sydney Basin sequence.

Jemidee Microgranodiorite (new name). Two large outcrops and five smaller southwest-northeast trending outcrops of the Jemidee Microgranodiorite have been mapped to the south of Bullio and Jemidee Stations (Fig. 1). These intrusions crop out poorly over an area of 4 km², and in many localities contacts have been inferred (Fig. 1). The Jemidee Microgranodiorite is named after Jemidee Station and the type locality is GR373949 on the Barrallier 1:25 000 Topographic Sheet.

Where visible most contacts are sharp, irregular and characterized by veins of microgranodiorite which intrude the country rock. At one contact with the Karalinga Formation (GR397297), large blocks (up to 2 m) of sandstone with contorted bedding are found within the microgranodiorite. Elsewhere, smaller irregularly-shaped xenoliths derived from country rock occur along contacts with the Rileys Ridge Rhyodacite Member and the Karalinga Formation. These xenoliths have biotite- and hornblende-rich rims. Pyrite, slickensides and well-developed non-systematic jointing also occur along contacts. Contacts with the Rileys Ridge Rhyodacite Member are characterized by partial recrystallization of the dacite groundmass.

The Jemidee Microgranodiorite is a fine-grained pale grey to green holocrystalline porphyritic microgranodiorite composed of phenocrysts of quartz (up to 10 mm), plagioclase and biotite in a fine-grained groundmass. Plagioclase phenocrysts are zoned with cores of andesine (An₃₈ to An₄₇) and more albitic outer rims (An₂₀ to An₂₅). Small phenocrysts of hornblende (pleochroic scheme — α = pale green, β = green, γ = brown to dark green) can be seen in thin-section. The groundmass comprises quartz, plagioclase, orthoclase and biotite. Accessory minerals include zircon, apatite, epidote and opaque minerals. Clinozoisite and chlorite occur as secondary minerals.

At GR364913 a leucogranitic phase characterized by more quartz and orthoclase and less mafic minerals than the dominant phase, crops out over an area of 500 m². Adjacent to this phase (at GR363913) and also cropping out at GR363912 and GR363914 (total outcrop area 1500 m²) is a foliated coarse-grained granodiorite with a higher percentage of mafic minerals.

The Tugalong Limestone Member has been extensively altered to a coarse- to medium-grained calc-silicate hornfels along the contact with the Jemidee Microgranodiorite. Green hornfels contains abundant colourless to pale green diopside and epidote; grey to pink hornfels has abundant tremolite and grossular garnet; and white hornfels comprises mostly wollastonite and calcite with minor amounts of quartz. Clinozoisite and biotite are found in the diopside-epidote hornfels.

At GR367915 a small outcrop of metamorphosed limestone is found within the Jemidee Microgranodiorite.

Mandari Granodiorite (new name). The Mandari Granodiorite, named after Mandari property, intrudes the Silurian Karalinga Formation and is unconformably overlain by the Mid-Permian Shoalhaven Group. Reconnaissance mapping has shown that this intrusion, which crops out over an area of 2 km² in the eastern part of the Bullio area (Fig. 1), extends southeast to Joadja. The type locality is located at GR413920 on the Hanworth 1:25 000 Topographic Sheet. Contacts with the Karalinga Formation are sharp with vein-like masses of finer-grained granodiorite cross-cutting the sedimentary rocks. A 20 m fine-grained hornfels aureole has developed in the Karalinga Formation and contains abundant red-brown biotite,

chlorite, quartz with inclusions of biotite, tourmaline and minor muscovite, sericitized plagioclase and pinite.

The Mandari Granodiorite is a coarse-grained, grey, holocrystalline granodiorite with large euhedral crystals of plagioclase (up to 12 mm in length), hornblende and anhedral grains of quartz and orthoclase. Staining with sodium cobaltinitrite and amaranth dye (Norman, 1974) shows that orthoclase is also interstitial to these minerals. Plagioclase has andesine (An_{35} to An_{45}) cores and oligoclase (An_{20}) rims. Dark green to black hornblende (pleochroic scheme — α = pale brown, β = brown and γ = dark brown) has inclusions of apatite, zircon (usually with faint pleochroic haloes) and opaque minerals. Accessory minerals include zircon, apatite and magnetite.

Xenoliths in the Mandari Granodiorite are of two types. Dark, rounded to elongate mafic xenoliths occur randomly distributed throughout the body and range in size from less than 50 mm to over 500 mm. These xenoliths are surrounded by a corona-like zone of large hornblende crystals and contain biotite and K-feldspar in equal amounts with lesser amounts of hornblende and plagioclase. The plagioclase is of similar composition to that in the granodiorite. Irregular elongated quartz-rich sedimentary xenoliths, derived from the country rock, occur near known and inferred contacts and are also randomly scattered throughout the granodiorite.

Numerous pink aplite veins cross-cut the granodiorite and xenoliths. Pegmatites with micrographic texture also occur within the Mandari Granodiorite.

Minor Intrusions. Two large dykes (GR418898 and GR416921) and several smaller dykes of weathered, medium-grained dacite with plagioclase phenocrysts up to 15 mm long, intrude the Mandari Granodiorite. A small intrusion of pink medium-grained porphyritic dacite of less than 200 m² outcrop area intrudes the Byrnes Creek Formation at GR372917 but does not appear to be related to the dykes. A distinct foliation has developed and abundant pyrite occurs in this porphyritic dacite near southeastern contact.

GEOCHEMISTRY

Chemical data for samples from the type localities of the Pulpit Rock Dacite Member, the Rileys Ridge Rhyodacite Member, the Jemidee Microgranodiorite and the Mandari Granodiorite were presented in Facer *et al.* (1980; analyses 11-14, table 1). The similarity in chemical data and the spatial relationships of these igneous rocks at Bullio suggests that they are genetically related. The two volcanic phases of the Bindook Complex which crop out in the Bullio district and the two igneous intrusions also have a close chemical affinity with other phases of the Bindook Complex given elsewhere (Joplin, 1943; 1971; David, 1950; Facer *et al.*, 1980; Fergusson, 1980). Chemical data for the two intrusive phases are consistent with those for I-type granites (Chappell and White, 1974; 1976).

AGE OF THE INTRUSIONS

The Jemidee Microgranodiorite intrudes both the Silurian Karalinga Formation and the Rileys Ridge Rhyodacite Member of the Bindook Complex, whereas the Mandari Granodiorite intrudes the youngest sub-unit of the Silurian sequence. Both are unconformably overlain by the Mid-Permian Shoalhaven Group.

Facer *et al.* (1980) have shown that chemical and heat generation data for the

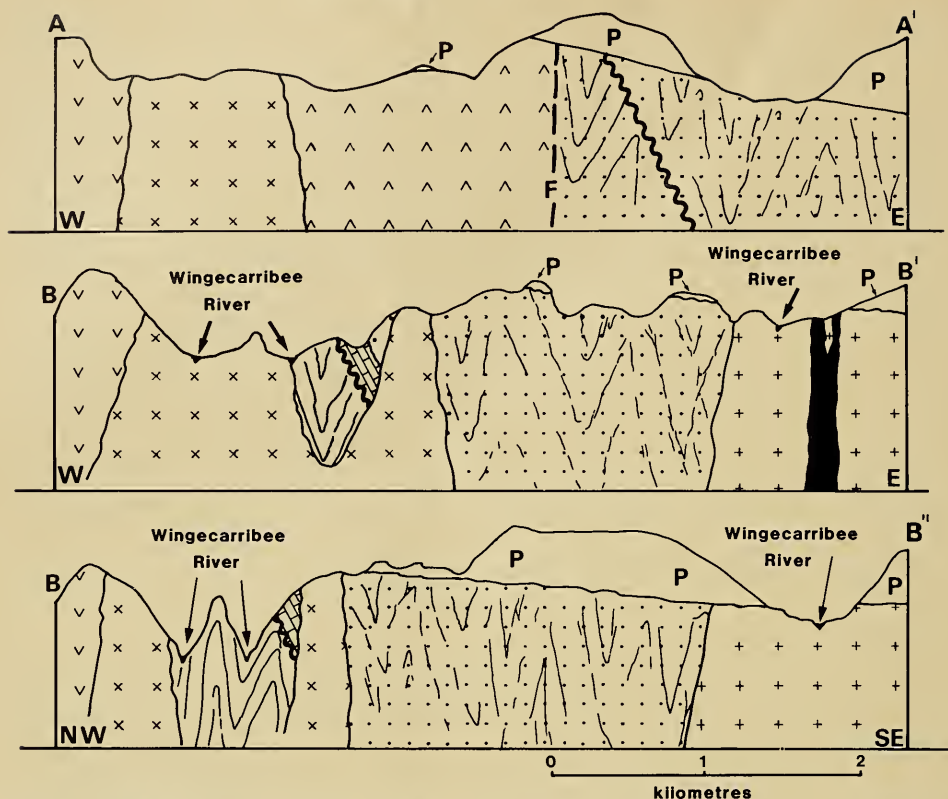


Fig. 3. Geological sections for the Bullio area. P — Permian, Sydney Basin sequence. Location of sections and other symbols are shown on Fig. 1.

four igneous phases at Bullio are consistent with data for other siliceous igneous rocks of Devonian age.

The Wollongong 1:250 000 Geological Map (Rose, 1966) showed the Marulan Batholith and Bindook Complex as southerly and northerly extremities, respectively, of a large north-south trending igneous complex. Chemical data for the igneous rocks of the Bullio area are similar to data for phases of the Marulan Batholith (Jones and Carr, pers. comm., 1980) which has been dated by Carr, Jones and Wright (1980) as Early Devonian (mean K-Ar date — 398M.Y.). A possible genetic relationship between the Marulan Batholith (and associated Tangerang volcanics) and the four igneous phases in the Bullio area is therefore likely. Jones and Carr (1980) suggested a nearly synchronous emplacement for the volcanic rocks and intrusions at Bungonia and similarly a nearly synchronous emplacement of the Jemidee Microgranodiorite, the Mandari Granodiorite and the volcanic rocks of the Bindook Complex is indicated at Bullio. An Early Devonian age is therefore favoured for both intrusions at Bullio.

STRUCTURAL HISTORY

Schematic geological cross-sections showing the major structural features of the Bullio district are given in Figs. 3 and 4.

Folding. Two scales of folding have been recognized in the Byrnes Creek Formation.

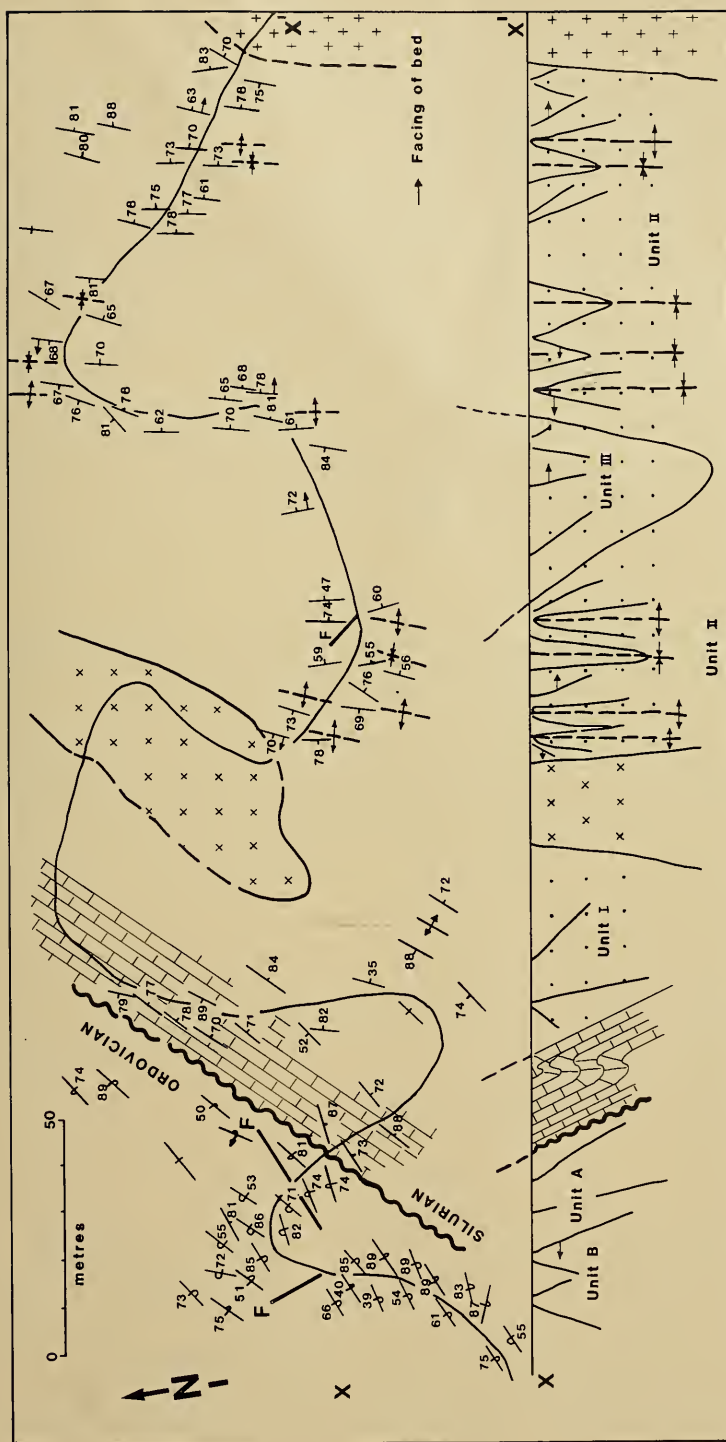


Fig. 4. Fold axes and schematic cross-section along portion of the Wingecarribee River. Locality and symbols are shown on Fig. 1.

Large-scale folding has gently plunging axial planes (for example approximately 10° towards 260° at GR372914) and has been recognized in well exposed outcrops of quartzarenite along the Wingecarribee River. Small-scale folds and small kink folds have developed in the black slates and fine-grained laminated quartzarenites of Units B and C of the Byrnes Creek Formation. These smaller folds plunge steeply and fold axes are not persistent along strike.

Medium- to small-scale tight asymmetrical folds have been recognized in the interbedded arenite and shale of the Karalinga Formation (Fig. 4). In small-scale folds, movement has occurred along strike-slip fault planes in the shale and there is a marked thickening of shale along fold hinges. Open small-scale folds have been recognized in the bedded arenites. Fold axes in both small-scale fold sets plunge to the north and to the south at angles of less than 20° . Both fold styles are thought to be expressions of the same folding event.

Open folds with shallow amplitudes and short wavelengths are found in the Tugalong Limestone Member. Axial plane cleavage, calcite-filled *en echelon* tension gashes and calcite-filled joints have developed in both the shale and limestone of this member. Differences in competence between the Tugalong Limestone Member and rocks of the overlying units can possibly account for the different fold styles that have developed during a single episode of folding.

The steeply-dipping folded Karalinga Formation may represent the western limb of a large syncline.

A well-defined cleavage, subparallel to bedding planes, has developed in the less competent slates and finely laminated quartzarenites of the Byrnes Creek Formation and in shales of Units I and II of the Karalinga Formation. Boudinage structures are found in the quartzarenites of Unit D of the Byrnes Creek Formation.

Faulting. Two large faults have been mapped in the area. A normal fault northwest of Tugalong Station is represented by a marked change in the type of vegetation and a termination of the limestone at GR374914. A second major fault is inferred along the vertical contact between the Byrnes Creek Formation and the Pulpit Rock Dacite Member with pronounced jointing, possibly representing an incipient shear zone, developed in both units. Quartz-filled veins and abundant pyrite are found in the quartzarenite at this contact.

Numerous small cross-cutting faults of up to 4 m lateral movement, are found in bedded quartzarenite (Units A and C) and in interbedded quartzarenite and shale (Unit D) of the Byrnes Creek Formation. Faults of similar dimensions are found in the Karalinga Formation. Those in the Tugalong Limestone Member are associated with calcite filled fracture zones.

Only the major faults are shown in Fig. 1.

DISCUSSION

Deep marine quartz-greywacke spread throughout the southern Lachlan Geosyncline during the Late Ordovician. These sediments (such as Unit B of Crook *et al.*, 1973, and the black shale-slate facies and overlying flysch sequence of Scheibner, 1973b) spread south and east of Yass and accumulated on the Monaro Slope and Basin near an inferred subduction zone on the eastern edge of the Lachlan Pre-Cratonic Province. The Byrnes Creek Formation at Bullio was deposited in a northern extension of this province. Large-scale isoclinal folds in Ordovician strata have been recognized at Bungonia (Carr, Jones, Kantsler *et al.*, 1980) and in the southeastern part of the Lachlan Fold Belt (Late Bolindian to Late Llandoveryan: Stauffer and

Rickard, 1966; Crook *et al.*, 1973) and have been attributed to the Benambran Orogeny. The age of the folding in the Ordovician Byrnes Creek Formation at Bullio has not been determined.

At Bullio Early Silurian graptolitic distal flysch strata, such as the "Jerrara Series" (Naylor, 1935; 1936; 1950) have not been recognized and the Karalinga Formation, which was deposited in shallow water, is the earliest Silurian unit. Uplift and erosion of the Byrnes Creek Formation predated the deposition of the Tugalong Limestone Member.

The eruption of calc-alkaline acid volcanics which spread discordantly over the Bullio portion of the Capertee Volcanic Arch during the Late Silurian or Early Devonian was responsible for the emplacement of the Bindook Complex. Volcanism was associated with high level intrusion of granitic rocks of the Mandari Granodiorite and Jemidee Microgranodiorite. These events were of regional extent; similar volcanism and granite have been recognized at Bungonia (Carr, Jones, Kantsler *et al.*, 1980) and at Yerranderie (Jones *et al.*, 1977; Fergusson, 1980).

The age of the major faults in the Bullio area is difficult to establish. Small-scale strike-slip faults, found only in the youngest unit of the Karalinga Formation may have been active during folding. The north-south trending fault near Tugalong Station is, however, younger than the folding in the Karalinga Formation.

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